

Contract Report

Outdoor Monitoring and High Voltage Bias Testing of Thin-Film Photovoltaic Modules

Year 2, Quarter 2 Report

FSEC-CR 1512-05

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Prepared for

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Introduction

Outdoor monitoring and High Voltage Bias Testing of Thin-Film Photovoltaic Modules has been undertaken through the project funded by NREL for a period of three years. This is the Year 2, Quarter 2 Report, FSEC-CR1512-05. This report is for the period January-March 2005. The report contains the tasks carried out to modify the data acquisition process and installation of remaining modules.

This work consists of the study of outdoor testing and monitoring of photovoltaic (PV) thin-film modules fabricated by First Solar (Glass/CdTe/Glass), Shell Solar (Glass/CIS/Glass), United Solar (a-Si on flexible substrate), Energy Photovoltaics (Glass/ a-Si/Glass), and Global Solar (CIS on flexible stainless steel foil substrate) with 2 additional crystalline silicon modules in the hot and humid climate of Florida.

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Data Acquisition

As mentioned in the earlier report, thin-film PV modules from the following US PV Manufacturers have been installed on the Florida Solar Energy Center (FSEC) high voltage test setup: (6+6+2)-First Solar (CdTe), (24+24)-Shell Solar (CIS), (20+20)-Uni-Solar (a-Si:H), (9+9) Energy Photovoltaics (a-Si). (1+1) Global Solar modules (CIS), (2) BP Solar (c-Si) modules and all the remaining modules from different companies were installed as controls.

First Solar (FS), Shell Solar (SS), Uni-Solar (USSC) and Energy Photovoltaics (EPV) modules are connected in series so as to reach a maximum open circuit voltage, Voc approaching +600V and -600V. The modules are connected across a load consisting of several resistors to provide an operational point near the maximum power point. A small resistor (1 Ω -50 W) and a shunt (depending on the module rating) have been connected in series with the resistive load. The voltage and current measurements are carried out across the small resistor and the shunt respectively. The two BP Solar modules are also connected in series. After consultation with NREL one of the modules was uninstalled and stored as a control. The two Global Solar modules are connected individually across an optimum load. Each array voltage and current output, solar irradiance, along with ambient temperature, back of the module temperature at two locations, relative humidity, UV index and wind speed are being monitored on a daily basis. This report provides the data collection, data restoration and modification process.

Data Collection

As described earlier, all the modules had been brought to horizontal position and tied in August 12, 2004 because of hurricane Charlie. The modules were uninstalled on Sep 2-3, 2004 because of hurricane Frances and were re-installed during Sep 13-20, 2004. The modules were again uninstalled on Sep 22-23, 2004 and re-installed during Sep 27-30, 2004 because of

hurricane Jeanne. Since hurricane warnings continued until mid-November 2004, all connections were not completed and data collection could not be initiated. All the modules and electrical circuits were completely reinstalled by the beginning of December 2004. After all the modifications, test data collection began on December 09, 2004.

PV Materials Lab has installed one datalogger with two multiplexers and another datalogger with one multiplexer to measure the various parameters. All the voltages, currents and temperatures are being monitored with the first datalogger using two multiplexers. Multiplexer 1 is used to collect all the voltages and some temperature data and multiplexer 2 is used to collect currents and temperature values. High voltage leakage currents and ambient parameters such as solar irradiance, relative humidity, ultraviolet radiation intensity, wind speed and pressure are monitored with the second datalogger. A new program with the capability of measuring all the new additional parameters was uploaded in the new datalogger. The program has been designed to measure some additional parameters instantly. Appendix 1 consists of a list of parameters provided by NREL, additional parameters measured at FSEC and the Excel spreadsheet format used for data analysis. The datalogger program has been provided in Appendix 2.

Some groups at FSEC report data at an interval less than a minute. Hence the time display format at present is “hh:mm:ss” representing hour, minutes and seconds. All the other dataloggers at FSEC use this format. NREL suggested changing the format to “hhmm”. Time display format was modified. However, only the colons could be removed but the seconds still remained. This change has been incorporated on the Shell Solar website. A program is being written to modify this to the NREL format.

An error in the time between the two dataloggers was found on February 10, 2005. The two dataloggers were synchronized as soon as this error was discovered. Prior to Feb 10, 2005 the second datalogger was almost 1 hour behind the first datalogger. The data prior to February 10, 2005, provided along with the report was corrected for the time difference between the two dataloggers and the data was provided to NREL. It is being provided again along with this report. A program is also being written and will be uploaded to correct the error in the earlier data on the websites.

After the installation of additional components viz. circuit breakers, shunts, connectors for I-V measurements in the circuit data acquisition was continued. The new data was compared with the data of the previous year. Reduction in the power was noticed for some of the arrays. To analyze this degradation, the current-voltage (I-V) characteristics of the whole arrays of the modules of each Company were measured with a Daystar DS100 I-V curve tracer. Since the First Solar and Shell Solar arrays showed substantial degradation, I-V measurements of the individual modules were carried out for those arrays. All the I-V data was submitted to NREL and is being provided again together with this report.

At regular intervals of time the voltage and current readings are measured at the datalogger and in the junction box at the same instant of time. The First Solar arrays operated with a load resistor value of 550 Ω during the last year. Since the optimum load for the First Solar Arrays was around 475 Ω , it was decided to obtain readings with the load resistor value of 475 Ω for the period between Dec 09, 2004 and Feb 12, 2005. The load resistor value for the First Solar arrays was changed to 550 Ω from 475 Ω on Feb 12, 2005. The data is being compared with the two values of load resistors.

One c-Si module and two Global Solar modules were installed and the data collection for these began on March 16, 2005. The Uni-Solar +600 V array was showing inaccurate voltage and current values at night and some current values during daytime. All the electrical

connections were checked for any loose contacts. Data was constantly monitored. The problem continued to occur occasionally. The data cable was replaced with a new one. Now the Uni-Solar +600 V data being collected has no discrepancies. One of the temperatures (T_{18}) and a voltage (V_9) of the Global Solar modules and current (I_{11}) of the c-Si module has some discrepancies. The data collection cables will be replaced to overcome the problem.

Discussions were held with NREL on March 11, 2004 to decide the suitable resistor values for each module series. The values of load resistor decided for each of the modules array are as follows:

Array	Resistor Value (Ω)	
	+600 V	-600 V
First Solar	350	375
Shell Solar	175	175
Uni-Solar	150	150
Energy Photovoltaic	350	375

Table 1: Load Resistor Values decided for each Array.

Salient points of the discussion are provided in the following: (A word file is being provided with the details of the conference call minutes.)

- 1) Change the load resistor values for FS, USSC and EPV arrays.
- 2) Measure the parameters at 5 sec intervals and record the average data at 15 min intervals.
- 3) Calibrate the pyranometer.
- 4) Plot the data at least once a week and analyze.
- 5) Compile data once a month and report.
- 6) If there is any discrepancy in the data file, add a text file to briefly describe it.
- 7) Check the alignment of the arrays and the pyranometer. Use digital leveler to align EAST-WEST also correct orientation in North-South direction.
- 8) Use Kapton or polyimide tape for temperature measuring thermocouples.

The following steps were taken to follow the instructions. The resistor values for FS, USSC and EPV arrays were changed to the suggested values shown in the above table on March 12, 2005. The data measurement interval was changed on the same day. Whenever the datalogger was shut off for maintenance in the junction box or data collection unit or for I-V measurements, no data is collected. An excel file containing these time intervals with comments is provided with this report. On the website, the data shows a value of 32767 when no data is being collected. In the data provided herewith these values have been replaced with blanks.

2-D plots for all the arrays for clear sunny days after the change of resistors were plotted and are provided with this report. From the graphs, the First Solar +600 V array power values were higher than those for the -600 V array. The EPV arrays were also showing some difference in the power values. This is due to different load resistor values. Therefore, EPV requested that values of both the load resistors should be 350 Ω . Therefore, after consultation with NREL, load resistor value for the EPV -600 V array was changed to 350 Ω . Now both +600 V and -600 V have the same resistor value. Variation of power, solar irradiance with time plots for the data with new load resistor for EPV will be provided with next monthly data report. It is suggested

that the load resistor values for the First Solar array -600 V should also be changed from 375 Ω to 350 Ω .

All the rows of various arrays were checked for proper angle alignment in the EAST-WEST direction. Most of the rows were in a $\pm 0.5^\circ$ range. Some of them were in a $\pm 1.5^\circ$ range. Adjustments were made so as to reduce the error in these rows on April 12, 2005. Now all arrays are in a $\pm 0.5^\circ$ range.

The pyranometer showed negative values at night. Hence the pyranometer was sent for calibration. A calibrated pyranometer was installed immediately to avoid loss of data. However, this also showed small negative values at night. The reason for the small negative values is provided below. A new pyranometer has been received and will be installed.

Why Pyranometer shows negative values at night?

The pyranometer sensor is exposed to sunrays. The irradiance values thus obtained are a function of the temperature difference between the sensor material and the case surrounding it. During daytime the sensor temperature varies with sunlight but the temperature of the case is same as that of the ambient temperature. At night, no sunrays are absorbed by the sensor. There is a possibility that the temperature of the sensor might be lower than the case temperature. Hence the pyranometer may show small negative values at night. If necessary, kindly provide comments regarding procedure to follow to avoid this.

Website Modifications

New websites for Energy Photovoltaics modules array, www.infomonitors.com/hpt/epv/, Global Solar array, <http://infomonitors.com/hpt/gs/> have been launched. All the other company websites along with the NREL websites have been modified. A new link for daily comments has been added to all the web pages. This section is still being updated. The power calculation formula for the data collected after December 12, 2004 is the product of voltage and current. Prior to this date the power calculation formula was the ratio of the square of the array voltage to the total resistor value (V^2/R). It is essential to choose the appropriate button on the web page to get power calculations depending on the date. Power calculations for the data after December 12, 2004 use V^2/R in the Summary* Report and a product of V and I (measured across a shunt) in the Summary** Report.

High Voltage (HV) Bias Testing

The study of leakage currents in high-voltage biased thin-film photovoltaic (PV) modules fabricated by First Solar (CdTe), Shell Solar (CIS) and Uni-Solar (a-Si:H) has also been undertaken as a part of this project for a period of three years. FSEC high voltage test bed consisting of two modules from each manufacturer, First Solar (CdTe), Shell Solar (CIS) and Uni-Solar (a-Si:H) were installed at +600 V and -600 V respectively at the FSEC high voltage test bed. Two modules from EPV have also been installed for HV bias testing.

Data Collection

As mentioned above due to hurricane warnings it was not possible to install the modules. The EPV modules were installed for HV bias testing together with the modules of First Solar, Shell Solar and Uni-Solar. It was not possible to collect data individually for the high voltage

biased modules during January-February 2005 because of circuit problems. These problems were resolved and data collection was reinitiated on Feb 26, 2005.

Visual Inspection

Visual inspections of the modules were carried out. No major changes were observed.

Planned Activities for Year 2 Quarter 3

- 1) Carry out data acquisition and provide data on monthly basis.
- 2) Take I-V Measurements for all the arrays once and provide the data.
- 3) Monitor and report any changes in the PV modules.

Appendix 1

OTF PV Systems Standard Campbell Data Output (starting Sept 2003)

Field	Parameter	Units	Excel Spreadsheet Column	FSEC Format
1	System ID		A	System ID
2	Year		B	Year
3	Day	Julian	C	Day
4	Time	MST 24hr clock	D	Time (EST)
5	POA Irradiance	W/m ²	E	Irradiance
6	DC Power	Watts	F	DC Pos Power
7	AC Power	Watts	G	AC Pos Power
8	DC Pos Voltage	Volts	H	DC Pos Voltage
9	DC Pos Current	Amps	I	DC Pos Current
10	DC Neg Voltage	Volts	J	DC Neg Voltage
11	DC Neg Current	Amps	K	DC Neg Current
12	AC Voltage	Volts	L	AC Voltage
13	AC Current	Amps	M	AC Current
14	Ambient Temp	deg C	N	Ambient Temp
15	Module 1 Temp	deg C	O	Module Pos Temp 1
16	Module 2 Temp	deg C	P	Module Pos Temp 2
17	Module 3 Temp	deg C	Q	Module Neg Temp 3
18	Inverter Temp	deg C	R	Inverter Temp
19		Watts	S	DC Neg Power
20		deg C	T	Module Neg Temp 4
21		deg C	U	Ref Temp
22		W/m ²	V	ULTVIO

Notes: Additional parameters specific to an individual system will be added on to the end of the Standard output format.
Zeros will be output to parameters that do not apply to a specific system.

Appendix 2

Program for Datalogger

```
;{CR10X}  
;{CR10X}  
;{CR10X}
```

*Table 1 Program

01: 5 Execution Interval (seconds)

;Ambient temperature measurement

1: Temp (107) (P11)

1: 1 Reps
2: 12 SE Channel
3: 3 Excite all reps w/E3
4: 1 Loc [TREF]
5: 1.0 Mult
6: 0.0 Offset

2: Set Port(s) (P20)

1: 8884 C8..C5 = input/input/input/10ms
2: 1418 C4..C1 = high/10ms/high/input

3: Beginning of Loop (P87)

1: 0000 Delay
2: 16 Loop Count

4: Do (P86)

1: 73 Pulse Port 3

5: Excitation with Delay (P22)

1: 1 Ex Channel
2: 0000 Delay W/Ex (units = 0.01 sec)
3: 10 Delay After Ex (units = 0.01 sec)
4: 0000 mV Excitation

;Temperature measurement(multiplexer1) for modules

6: Thermocouple Temp (DIFF) (P14)

1: 1 Reps
2: 1 2.5 mV Slow Range
3: 2 DIFF Channel
4: 1 Type T (Copper-Constantan)
5: 1 Ref Temp (Deg. C) Loc [TREF]
6: 2 -- Loc [T1]

7: 1.0 Mult
8: 0.0 Offset

7: End (P95)

8: Beginning of Loop (P87)

1: 0 Delay
2: 16 Loop Count

9: Do (P86)

1: 75 Pulse Port 5

10: Excitation with Delay (P22)

1: 1 Ex Channel
2: 0000 Delay W/Ex (units = 0.01 sec)
3: 10 Delay After Ex (units = 0.01 sec)
4: 0000 mV Excitation

11: Thermocouple Temp (DIFF) (P14)

1: 1 Reps
2: 1 2.5 mV Slow Range
3: 3 DIFF Channel
4: 1 Type T (Copper-Constantan)
5: 1 Ref Temp (Deg. C) Loc [TREF]
6: 18 -- Loc [T17]
7: 1.0 Mult
8: 0.0 Offset

12: End (P95)

13: Set Port(s) (P20)

1: 9999 C8..C5 = nc/nc/nc/nc
2: 0909 C4..C1 = low/nc/low/nc

14: Set Port(s) (P20)

1: 9999 C8..C5 = nc/nc/nc/nc
2: 1919 C4..C1 = high/nc/high/nc

;Voltage measurement for modules

15: Beginning of Loop (P87)

1: 0000 Delay
2: 16 Loop Count

16: Do (P86)

1: 73 Pulse Port 3

17: Excitation with Delay (P22)

1: 1 Ex Channel
2: 0000 Delay W/Ex (units = 0.01 sec)
3: 10 Delay After Ex (units = 0.01 sec)
4: 0000 mV Excitation

18: Volt (Diff) (P2)

1: 1 Reps
2: 5 2500 mV Slow Range
3: 1 DIFF Channel
4: 34 -- Loc [V1]
5: 1.0 Mult
6: 0.0 Offset

19: End (P95)

;current measurement for modules

20: Beginning of Loop (P87)

1: 0000 Delay
2: 16 Loop Count

21: Do (P86)

1: 75 Pulse Port 5

22: Excitation with Delay (P22)

1: 1 Ex Channel
2: 0000 Delay W/Ex (units = 0.01 sec)
3: 10 Delay After Ex (units = 0.01 sec)
4: 0000 mV Excitation

23: Volt (Diff) (P2)

1: 1 Reps
2: 5 2500 mV Slow Range
3: 4 DIFF Channel
4: 50 -- Loc [I1]
5: 1.0 Mult
6: 0.0 Offset

24: End (P95)

25: Set Port(s) (P20)

1: 9999 C8..C5 = nc/nc/nc/nc
2: 0909 C4..C1 = low/nc/low/nc

26: Z=X*F (P37)
1: 34 X Loc [V1]
2: 0.351 F
3: 34 Z Loc [V1]

27: Z=X*F (P37)
1: 35 X Loc [V2]
2: 0.376 F
3: 35 Z Loc [V2]

28: Z=X*F (P37)
1: 36 X Loc [V3]
2: 0.176 F
3: 36 Z Loc [V3]

29: Z=X*F (P37)
1: 37 X Loc [V4]
2: 0.176 F
3: 37 Z Loc [V4]

30: Z=X*F (P37)
1: 38 X Loc [V5]
2: 0.151 F
3: 38 Z Loc [V5]

31: Z=X*F (P37)
1: 39 X Loc [V6]
2: 0.151 F
3: 39 Z Loc [V6]

32: Z=X*F (P37)
1: 40 X Loc [V7]
2: 0.351 F
3: 40 Z Loc [V7]

33: Z=X*F (P37)
1: 41 X Loc [V8]
2: 0.351 F
3: 41 Z Loc [V8]

34: Z=X*F (P37)
1: 42 X Loc [V9]
2: 0.016 F
3: 42 Z Loc [V9]

35: Z=X*F (P37)

1: 43 X Loc [V10]
2: 0.016 F
3: 43 Z Loc [V10]

36: Z=X*F (P37)
1: 44 X Loc [V11]
2: 1 F
3: 44 Z Loc [V11]

37: Z=X*F (P37)
1: 45 X Loc [V12]
2: 1 F
3: 45 Z Loc [V12]

38: Z=X*F (P37)
1: 46 X Loc [V13]
2: 1 F
3: 46 Z Loc [V13]

39: Z=X*F (P37)
1: 47 X Loc [V14]
2: 1 F
3: 47 Z Loc [V14]

40: Z=X*F (P37)
1: 48 X Loc [V15]
2: 1 F
3: 48 Z Loc [V15]

41: Z=X*F (P37)
1: 49 X Loc [V16]
2: 0.00366 F
3: 49 Z Loc [V16]

42: Z=X*F (P37)
1: 50 X Loc [I1]
2: 0.02 F
3: 50 Z Loc [I1]

43: Z=X*F (P37)
1: 51 X Loc [I2]
2: 0.02 F
3: 51 Z Loc [I2]

44: Z=X*F (P37)
1: 52 X Loc [I3]

2: 0.1 F
3: 52 Z Loc [I3]

45: Z=X*F (P37)
1: 53 X Loc [I4]
2: 0.1 F
3: 53 Z Loc [I4]

46: Z=X*F (P37)
1: 54 X Loc [I5]
2: 0.1 F
3: 54 Z Loc [I5]

47: Z=X*F (P37)
1: 55 X Loc [I6]
2: 0.1 F
3: 55 Z Loc [I6]

48: Z=X*F (P37)
1: 56 X Loc [I7]
2: 0.02 F
3: 56 Z Loc [I7]

49: Z=X*F (P37)
1: 57 X Loc [I8]
2: 0.02 F
3: 57 Z Loc [I8]

50: Z=X*F (P37)
1: 58 X Loc [I9]
2: 0.1 F
3: 58 Z Loc [I9]

51: Z=X*F (P37)
1: 59 X Loc [I10]
2: 0.1 F
3: 59 Z Loc [I10]

52: Z=X*F (P37)
1: 60 X Loc [I11]
2: 0.1 F
3: 60 Z Loc [I11]

53: Z=X*F (P37)
1: 61 X Loc [I12]
2: 1 F

3: 61 Z Loc [I12]

54: Z=X*F (P37)

1: 62 X Loc [I13]

2: 1 F

3: 62 Z Loc [I13]

55: Z=X*F (P37)

1: 63 X Loc [I14]

2: 1 F

3: 63 Z Loc [I14]

56: Z=X*F (P37)

1: 64 X Loc [I15]

2: 1 F

3: 64 Z Loc [I15]

57: Z=X*F (P37)

1: 65 X Loc [I16]

2: 1 F

3: 65 Z Loc [I16]

58: If time is (P92)

1: 0000 Minutes (Seconds --) into a

2: 15 Interval (same units as above)

3: 10 Set Output Flag High (Flag 0)

59: Set Active Storage Area (P80)

1: 1 Final Storage Area 1

2: 200 Array ID

60: Real Time (P77)

1: 1110 Year,Day,Hour/Minute (midnight = 0000)

61: Average (P71)

1: 65 Reps

2: 1 Loc [TREF]

62: Do (P86)

1: 20 Set Output Flag Low (Flag 0)

*Table 2 Program

02: 0.0000 Execution Interval (seconds)

*Table 3 Subroutines

End Program

-Input Locations-

1 TREF	1 3 1
2 T1	1 1 1
3 T2	1 1 0
4 T3	1 1 0
5 T4	1 1 0
6 T5	1 1 0
7 T6	1 1 0
8 T7	1 1 0
9 T8	1 1 0
10 T9	1 1 0
11 T10	1 1 0
12 T11	1 1 0
13 T12	1 1 0
14 T13	1 1 0
15 T14	1 1 0
16 T15	1 1 0
17 T16	1 1 0
18 T17	1 1 1
19 T18	1 1 0
20 T19	1 1 0
21 T20	1 1 0
22 T21	1 1 0
23 T22	1 1 0
24 T23	1 1 0
25 T24	1 1 0
26 T25	1 1 0
27 T26	1 1 0
28 T27	1 1 0
29 T28	1 1 0
30 T29	1 1 0
31 T30	1 1 0
32 T31	1 1 0
33 T32	1 1 0
34 V1	1 2 2
35 V2	1 2 1
36 V3	1 2 1
37 V4	1 2 1
38 V5	1 2 1
39 V6	1 2 1
40 V7	1 2 1
41 V8	1 2 1
42 V9	1 2 1

43 V10	1 2 1
44 V11	1 2 1
45 V12	1 2 1
46 V13	1 2 1
47 V14	1 2 1
48 V15	1 2 1
49 V16	1 2 1
50 I1	1 2 2
51 I2	1 2 1
52 I3	1 2 1
53 I4	1 2 1
54 I5	1 2 1
55 I6	1 2 1
56 I7	1 2 1
57 I8	1 2 1
58 I9	1 2 1
59 I10	1 2 1
60 I11	1 1 1
61 I12	1 1 1
62 I13	1 1 1
63 I14	1 1 1
64 I15	1 1 1
65 I16	1 1 1

-Program Security-

0000

0000

0000

-Mode 4-

-Final Storage Area 2-

0

-CR10X ID-

0

-CR10X Power Up-

3